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Effect of fisher's soak tactic on catch pattern in the Danish gillnet plaice fishery

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Bycatch; Discard minimization; Fishing tactics; Gillnet; Catch comparison

ABSTRACT

Soak duration in the gillnet fisheries can vary from a few hours to several days. The industry reports a variation of soak tactics between target species, but also between seasons for the same species. These are determined by the robustness of the target species and the catch of unwanted species. Different soak tactics were compared to estimate the role that the choice of a soak tactic plays in the catch efficiency of both target and unwanted species. In the Danish summer gillnet fishery targeting plaice *(Pleuronectes platessa)*, nets are deployed approximately 12 hours (h) during day. Unwanted species are common dab (*Limanda limanda*) and edible crab (*Cancer pagurus*). The commercially used 12 h deployment during day was compared to 12 h deployment during night and 24 h deployment. On average, there were about 1.5 more catches of commercial size plaice (above 27cm), and 2 and 4 times less catches of the unwanted dab and edible crab, respectively, for 12 h at day compared to the other soak tactics (12 h at night or 24 h). Gillnetters participating in the coastal summer fishery for plaice follow the theoretical optimal soak tactic. The commercially used 12 h deployment during day maximises the catch of commercial sized plaice and limits handling time by catching less unwanted dab and crabs.

1. Introduction

Approximately 40% of the European fishing vessels deploy set gillnets as main fishing gear (E.C., 2017). In Denmark, gillnetters represents approximately 90% of the fishing fleet. Many of the European gillnetters participate in small-scale fisheries and play a vital role in the coastal areas (Veiga et al., 2016). Gillnets are, in general, considered to be highly size selective, with larger mesh sizes catching larger fish (Stergiou and Erzini, 2002; He and Pol, 2010). All species are not, however, equally vulnerable to the gear (Fonseca et al., 2002; Valdemarsen and Suuronen, 2003; He and Pol, 2010; Breen et al., 2016). Limiting unwanted species is in the fisher's interest as it reduces handling time, which can be intensive in gillnet fisheries. Handling time affects the fishing power, i.e., the number and length of gillnets that can be handled during a fishing trip (Morandeau et al., 2014; Fauconnet and Rochet, 2016). The selection properties of gillnets may be improved by altering mesh size, netting material, or twine size. But due to the nature of the gear, one would most likely also impair the catch efficiency of the net. More complex gears proved to successfully reduce bycatch, e.g., gillnets that float above the seabed (norsel-mounted nets) to reduce bycatch of red king crab (*Paralithodes camtschaticus*) in the cod (*Gadus morhua*) fishery (Godøy et al., 2003), but are usually limited in passive fisheries (Kennelly and Broadhurst, 2002; Andersen et al., 2012; Eliasen et al., 2014; Fauconnet et al., 2015; Breen et al., 2016; Fauconnet and Rochet, 2016). In many cases, the fisher's operational tactic plays a dominant role. It also has the advantage of no additional capital cost (Sigurðardóttir et al., 2015).

Soak duration in the gillnet fisheries varies considerably. In Denmark, it can be from a few hours in the wreck fishery for cod to several days in the turbot (*Scophthalmus maximus*) or monkfish (*Lophius piscatorius*) fisheries. It can even vary between seasons for the same species. Time of day and soak duration are easily adjustable factors which appear to play a key role in the gillnet fisheries. Previous studies suggested a relationship between soak time and catch size for short soak times (up to 6 h) but none for longer soak times (Acosta, 1994; Gonçalves et al., 2008; Hickford and Schiel, 1996; Losanes et al., 1992; Minns and Hurley, 1988; Rotherham et al., 2006; Schmalz and Staples, 2014). The soak tactic should ensure an acceptable catch rate of commercial species to optimize landings with regard to fishing effort, fuel consumption and labour cost (Hickford and Schiel, 1996; Hopper et al., 2003). The theoretical optimal soak tactic in a given gillnet fishery is the one that best maximizes catches of target species while minimizing unwanted catch. However, not all fishing tactics are associated with catch maximization. Some fishers are satisfied with recovering the operating costs only, or minimizing physical and economic risks (Salas and Gaertner, 2004). This can especially be relevant in small-scale fisheries, which represent a majority of the gillnetters (Salas and Gaertner, 2004).

To investigate the effect of soak tactic on catch pattern in the gillnet fisheries, the following questions were addressed:

- What role does the choice of soak tactic play in the catch pattern, i.e., how big is the difference in catches of target and unwanted species between different soak tactics employing differences in time of the day and duration?
- If the catch efficiency is different, is this difference size dependent?
- Are the fishers able to adjust to use the theoretical optimal soak tactic?

We used the Danish summer plaice (*Pleuronectes platessa*) gillnet fishery in the Skagerrak (ICES area IIIa) as a case study. The plaice fishery in the Skagerrak is one of the most important commercial gillnet fisheries in Denmark (Ulrich and Andersen, 2004). It takes place in coastal sandy and shallow fishing grounds. It is characterized by shorter soaks in the summer compared to the winter to reduce the excessive bycatch of edible crabs (*Cancer pagurus*). Pincers of the larger edible crabs can be sold, but crabs are mostly seen as a nuisance by gillnetters as they can severely increase handling time. It is common practice to crush the larger crabs in order to facilitate their disentanglement from the netting. Most of the other non-target species, such as dab (*Limanda limanda*), usually represent low selling value at the fish auction. We carried out a gillnet experiment following commercial practices with three different soak tactics, i.e., the commercially used 12 hours (h) during day, as well as 12 h at night and 24 h to document differences in species composition, catch efficiency and specifically examine whether the fishermen have adopted the best theoretical soak tactic.

2. Materials and methods

2.1. Experimental design and sea trials

Trials were conducted on the Danish commercial gillnetter Skovsmose HG5 (11.99m, 171kW) for eight consecutive days in September 2014. A total of 27 identical plaice gillnets (http://daconet.dk/) with all specifications corresponding to commercial practice were used (Table 1). A total of nine fleets each consisting of three gillnets tied together were constructed. Every day, three fleets were soaked for 24 h. Simultaneously, three fleets were soaked for 12 h during the day and three others during the night (Fig. 1 and 2). The soak durations of 12 and 24 h covered the usual range of commercial practices in Danish coastal waters. Gillnets were set at a known sandy bottom habitat at the same depth. Soak tactics were alternated at each position. Fleets were positioned with the current, parallel to the coast, and anchored at both ends using 6 m bridle lines and 4 kg anchors following commercial practices. Fleets were hauled according to commercial practices using a hydraulically-powered net hauler with top roller (http://www.net-op.dk/). Two fishers disentangled the catch from the netting on a sorting table during hauling.

2.2. Data collection

All fish and invertebrate mega-fauna were sorted to species level and counted. Fish total length was measured to the nearest cm below on a measuring board (E.U., 2016). Invertebrates were measured with a caliper to the nearest mm below as carapace width for edible (*Cancer pagurus*), common (*Carcinus maenas*) and swimming (*Liocarcinus depurator*) crabs (ICES, 2015). Carapace height was measured for hermit crabs (*Pagurus bernhardus*). Diameter was measured for common (*Asterias rubens*), Northern (*Leptasterias muelleri*) and spiny (*Marthasterias glacialis*) starfish and edible sea urchin (*Echinus esculentus*). Data were collected at the fleet level to account for the between-fleet variation (Millar and Anderson, 2004). It was not always possible to process invertebrates as soon as they were hauled aboard and some were therefore kept in the vessel cooling room or frozen for later analysis.

2.3. Species composition

Relative abundance was calculated per fleet as the ratio between the number of individuals of a given species and the total number of individuals. Species occurrence was calculated as the ratio between the number of fleets where a given species was present and the total number of fleets (per soak tactic).

2.4. Catch comparison analysis

The method developed by Herrmann et al. (2017) for investigating the effect of design changes on catch efficiency in passive gears was used. The catch comparison analysis aimed to determine whether; (1) there was a significant difference in the catch efficiency between the different soak tactics tested, and (2) a potential difference between the different soaks could be related to the size of the individuals. Catch data of each soak tactic were summed over the different fleets to account for the variability in numbers and sizes of the individuals available at the specific time and position of each fleet's deployment. The experimental summed catch comparison rate cc_l is given by:

$$cc_l = \frac{\sum_{j=1}^{bq} nb_{lj}}{\sum_{i=1}^{aq} na_{li} + \sum_{j=1}^{bq} nb_{lj}} \qquad (1)$$

where na_{li} and nb_{lj} are the numbers of individuals measured in each length class l for soak tactic a in fleet i and for soak tactic b in fleet j, respectively. aq and bq are the number of fleets deployed with soak tactics a and b, respectively. aq and bq were identical in our experiment (3 fleets x 7 cruise days for each soak tactic).

The experimental cc_l is often modelled by the function $cc(l, \boldsymbol{v})$, or catch comparison curve, which expresses the probability of finding a fish of length l in one of the fleets of soak tactic b given that it was found in one of the fleets of soak tactic a or b. $\boldsymbol{v}$ represents the parameters describing the catch comparison curve. The function $cc(l, \boldsymbol{v})$ has the following form:

$$cc(l, \boldsymbol{v}) = \frac{exp\left(f(l, v_0, \ldots, v_k)\right)}{1 + exp\left(f(l, v_0, \ldots, v_k)\right)} \qquad (2)$$

where f is a polynomial of order k with coefficients v_0 to v_k. The values of the parameters $\boldsymbol{v}$ describing $cc(l, \boldsymbol{v})$ are estimated by minimizing the following equation:

$$-\sum_l \left\{ \sum_{i=1}^{aq} na_{li} \times \ln\left(1.0 - cc(l, \boldsymbol{v})\right) + \sum_{j=1}^{bq} nb_{lj} \times \ln\left(cc(l, \boldsymbol{v})\right) \right\} \qquad (3)$$

where the inner summations represent the summations of the data from the fleets and the outer summation is the summation over the length classes l.

The method developed by Herrmann et al. (2017) accounts for multiple competing models to describe the data using multi-model inference and therefore accounts for the uncertainty in model selection (Burnham and Anderson, 2002). f was considered up to an order of 4 with parameters v_0 to v_4. Leaving out one or more of the parameters $v_0 \ldots v_4$ led to 31 additional models that were considered as potential models for the catch comparison $cc(l, \boldsymbol{v})$ between a and b. The models were ranked and weighed according to their AICc values. AICc are AIC values corrected for finite sample sizes in the data (Akaike, 1974; Burnham and Anderson, 2002). The combined model for the estimation of $cc(l,\boldsymbol{v})$ resulting from the multi-model averaging was calculated by:

$$cc(l,\boldsymbol{v}) = \sum_i w_i \times cc(l,\boldsymbol{v}) \text{ with } w_i = \frac{exp\left(0.5\times\left(AICc_i - AICc_{min}\right)\right)}{\sum_j exp\left(0.5\times\left(AICc_j - AICc_{min}\right)\right)} \quad (4)$$

where the summations are over the models with a AICc value within +10 of the model with the lowest AICc value ($AICc_{min}$) (Katsanevakis, 2006; Herrmann et al., 2014).

Contrary to the catch comparison rate *cc(l,* $\boldsymbol{v}$*)*, the catch ratio *cr(l,*$\boldsymbol{v}$*)* gives a direct relative value of the catch efficiency between the soak tactics *a* and *b*, e.g., if the catch efficiency of both soak tactics is equal, *cr(l,*$\boldsymbol{v}$*)* should be 1.0. The catch ratio *cr(l,*$\boldsymbol{v}$*)* is related to the summed catch comparison, and was calculated in its functional form in addition to the catch comparison rate as follow (for further details, see Herrmann et al., 2017):

$$cr(l,\boldsymbol{v}) = \frac{aq\times cc(l,\boldsymbol{v})}{bq\times\left(1-cc(l,\boldsymbol{v})\right)} \quad (5)$$

The Efron 95% confidence limits for both the catch comparison rate and the catch ratio were estimated using 1000 bootstrap repetitions (Efron, 1982). Applying double bootstrapping method accounts for:

(1) between-fleet variation in the availability of fish and catch efficiency, by randomly selecting *aq* and *bq* fleets from the pool of fleets of soak tactics *a* and *b*, respectively (initial resampling), and
(2) within-fleet uncertainty in the size structure of the catch data, by randomly selecting fish from each fleet, with a total number of fish similar to that sampled in the fleet (bootstrapping of the initial resampling).

As the combined model method was applied to each bootstrap repetition, the effect of uncertainty in model selection was also accounted for in the confidence limits.

The ability of the combined model to describe the experimental data was evaluated based on the p-value. It quantifies the probability of obtaining by chance a difference at least as large as the one observed between the experimental data and the model, assuming that the model is correct. The p-value should therefore not be <0.05 for the combined model to describe the experimental data sufficiently well. To identify sizes with significant difference in catch efficiency, length classes in which the confidence limits for the combined catch comparison curve did not contain *bq/(aq + bq)*, i.e., 0.5 in our case, were checked for.

One may logically assume a linear relationship between soak duration and the amount of catches, i.e., two times more catches for 24 h than for 12 h. Therefore, when comparing 24 h to 12 h, the expected catch ratio was calculated if, for 24 h, the catch rate was twice as high than for 12 h at day (2 x12 h D) or 12 h at night (2 x 12 h N). Another logical approach is to consider that the resulting catches after 24 h are the sum of the catches for 12 h at day and 12 h at night. Therefore, when comparing 24 h to 12 h, the expected catch ratio was calculated if, for 24 h there were to be the summed amount of catches caught for 12 h at day and 12 h at night (12 h D + 12 h N). For the calculation of the expected catch ratio, the $cr(l,\mathbf{v})$ given when comparing 12 h at night to 12 h at day for the length class representative of the main bulk of catches was used.

A length-integrated average value for the catch ratio was also estimated by:

$$cr_{average} = \frac{\frac{1}{bq}\sum_{l}\sum_{j=1}^{bq} nb_{lj}}{\frac{1}{aq}\sum_{l}\sum_{i=1}^{aq} na_{li}} \qquad (6)$$

where the outer summation covers the length classes in the catch during the experimental sea trials. The Efron 95% confidence limits for $cr_{average}$ was assessed by incorporating it into each of the bootstrap iterations. $cr_{average}$ is specific for the population structure encountered during the experimental sea trials. For the target species plaice, $cr_{average}$ was estimated for fish below and above Minimum Conservation Reference Size (MCRS), also previous Minimum Landing Size (MLS), i.e., 27 cm.

Only the three most abundant and commonly occurring species, i.e., plaice, dab and edible crab were looked at in the catch comparison analysis. The lower and upper length classes were set as the nearest multiple of 5 of the minimal and maximal observed values for all soak tactics respectively, for each of the three species, i.e., 20 - 55 cm for plaice, 15 - 40 cm for dab and 55 - 200 mm for crabs. The number of individuals caught per length class for the three different soak tactics were compared as follows; 12 h at night compared to 12 h at day, 24 h compared to 12 h at day, and 24 h compared to 12 h at night. For the calculation of the expected catch ratios, the $cr(l,\mathbf{v})$ given when comparing 12 h at night to 12 h at day for the length class representative of the main bulk of catches was used, i.e. 35 cm for plaice, 25 cm for dab and 115 mm for crab.

2.5. Software

Catch comparison analysis were performed by SELNET (Herrmann et al., 2012). Graphs were produced by the open-source software R 3.2.3 (R Core Team, 2016) using the packages 'dplyr' (Wickham and François, 2015) and 'ggplot2' (Wickham, 2009).

4. Results

4.1. Description of the data and species composition

Fleets were set at an average depth of 5.4 m ± 0.6 m representative of shallow summer fishing grounds in the Danish coastal gillnet fishery. The average soak duration was 23.8 ±1.2 h for the 24 h fleets, 10.7 h ± 0.9 h for the 12 h at day fleets, and 12.4 h ± 1.1 h for the 12 h at night fleets (Fig. 2).

There was a total of 2431 fish and 1512 invertebrates caught and assessed onboard the fishing vessel from 63 different fleets (3 soak patterns x 3 fleets x 7 sampling days). There were 19 and 8 different species caught for fish and invertebrates respectively, all fleets included (Table 2). The number of individuals per fleet was highly variable (Table 2).

Overall, species composition between soak tactics was similar (Table 2). Plaice, common dab and edible crab were the most abundant species for all soak tactics. Plaice, dab and edible crab were also the most commonly occurring species for all soak tactics.

4.2. Catch comparison analysis

The catch comparison curves properly reflected the trend in the experimental points (Fig. 4). The experimental rates were subject to increasing binomial noise outside the length classes representing the main bulk of the catches (Fig. 3). The ability of the catch comparison curves to describe the experimental data was also verified by the fit statistics with all but one p-value > 0.05 (Table 3). The p-value slightly below 0.05 (12 h at night compared to 12 h at day for plaice with a p-value of 0.0399) was not considered a serious issue. As there was no systematic pattern in the deviation between the experimental and estimated rates, such a p-value was assumed a result of over dispersion in the data. All results described below were when looking at the main bulk of the catches within reasonably narrow confidence limits.

The results for plaice indicated lower catches for 12 h at night compared to 12 h at day, as the catch ratio was below 1.0. However, these results were not statistically significant due to wide confidence limits (Table 3, Fig. 3). An indication of lower catches for 24 h compared to 12 h at day was also found for smaller individuals. But again, these results were not significant due to wide confidence limits (Table 3, Fig. 3). The results indicated higher catches for 24 h compared to 12 h at night, with no length dependency, but without any significant difference (wide confidence limits) (Table 3, Fig. 3). When comparing 24 h to 12 h at day, for the main bulk of the catches, the estimated catch ratio for 24 h was significantly lower than the expected catch ratio 2 x 12 h D (catch rate twice as high), but not significantly different from 12 h D + 12 h N (summed amount of catches) (Fig. 4). When comparing 24 h to 12 h at night, for the main bulk of the catches, the estimated catch ratio for 24 h was significantly lower than the expected catch ratio 12 h D + 12 h N (summed amount of catches), but not significantly different from 2 x 12 h N (catch rate twice as high) (Fig. 3). This meant that catches for 12 h at night were indeed significantly different from those for 12 h at day. This also confirmed the previous observation of lower catches for 12 h at night compared to 12 h at day. On average, there were 52% and 35% less catches of individuals below and above MCRS respectively, for 12 h at night compared to 12 h at day (Table 3, Fig. 4).

The results for dab showed no difference between 12 h at night and 12 h at day (Table 3, Fig. 3). There were significantly higher catches for 24 h compared to both 12 h at day and 12 h at night (Table 3, Fig. 3). On average, there were twice as many catches for 24 h compared to 12 h at day and night (Table 3, Fig. 4). There was no strong indication of a length dependency in the data (Fig. 3).

The results for edible crab showed significantly higher catches for both 12 h at night and 24 h compared to 12 h at day (Table 3, Fig. 3). On average, there were four and five times more catches for 12 h at night and 24 h respectively, than 12 h at day (Table 3, Fig. 4). The results showed no difference between 12 h at night and 24 h (Table 3, Fig. 3). There was no strong indication of a length dependency in the data (Fig. 3).

5. Discussion

27 different species were caught in the gillnets, but in very limited numbers compared to the target plaice and the unwanted species crab and dab. Plaice, crab and dab were therefore driving the fishing tactic.

A significant variation in catch efficiency was found between the tested soak tactics. On average, there were about 1.5 times more catches of the target species plaice above 27cm for 12 h at day compared to the other soak tactics. Plaice usually show nocturnal behaviours (Froese and Pauly, 2015) but the current results do not support this. Contrary to plaice, there was no difference in the availability of dab to the gear between day and night. There was a simple relationship between catches and soak duration with twice as many catches for 24 h compared to 12 h (both day and night). On average, there were about 4 times less catches of the unwanted edible crab for 12 h at day compared to the other soak tactics. The differences in the availability of edible crabs to the gear were probably a result of the night effect and not the soak duration. Indeed, observations in the Skagerrak have shown that edible crabs prefer to forage in shallow water at night (Karlsson and Christiansen, 1996). With such a difference in catch efficiency on a limited time scale, soak tactics are a powerful tool for fishers to adjust to different fishing conditions.

Regarding length dependency, there was an indication of a higher probability for smaller individuals to be caught at day than at night. Indeed, it was observed in a laboratory study that the behavior of juvenile plaice in the light was dominated by swimming on the sand surface, with little activity on the bottom during darkness (Burrows, 1994). . The indication of lower catches for 24 h compared to 12 h at day was surprising as it would be reasonable to expect at least the same amount of catches as for half of the soak duration. This could be explained by the availability of small plaice concentrated on few sampling days at day time. There was no strong indication of a size dependency in the data for dab or for crab.

The theoretical optimal soak tactic in a given gillnet fishery is the one that best maximize catches of target species while minimizing unwanted catch. Together with avoiding unwanted catch of crab and dab, gillnetters targeting plaice in the observed coastal summer fishery managed to maximize their catch of the target species using shorter soaks in daylight (12 h at day). Fishers also have an economic interest in reducing the soak duration to prevent quality degradation of the entangled catch by scavengers and predators common in passive fishing gears (Borges *et al.*, 2001; Morandeau *et al.*, 2014; Savina *et al.*, 2016).

The experiment intended to evaluate commercial practices in the summer plaice gillnet fishery in the shallow Skagerrak fishing grounds. However, the use of soak tactics as an efficient tool for fishers to adjust to different fishing conditions are expected in other fisheries, seasons or areas, e.g., to avoid hagfish (*Myxinidae spp.*) or amphipods (*Amphipoda spp.*) in deeper waters.

Individual fishing experience was reported to be an important factor in relation to catch efficiency (Salas and Gaertner, 2004). Fishers use their experience to optimize their income under changing conditions. By using the substantial differences in catch efficiency provided by an alteration to their soak tactics, gillnetters have the ability to adjust to diverse fishing conditions much more easily and efficiently than by changing the characteristics of their gear. The understanding and documentation of such fishing strategies are essential to be able to evaluate and explore potential effects of relevant management measures by assessing the ability of fishers to adjust to new circumstances. For example, with the new landing obligation, fishers in Denmark using mesh sizes between 80 and 120 mm full mesh in the sole (*Solea solea*) fishery are facing larger bycatch of regulated round fish. They have started to change their soak tactics, which could be described as a "real time monitoring" of discards. Several fleets are soaked in the same time, one being lifted at regular intervals to check for the amount of unwanted catch (Chairman of Hirtshals fishermen organization, *Pers. Com.*).

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Table 1. Specifications of an individual net panel used in the experimental set-up. Height is given as stretched height.

Gear specifications		
Net	Type	Gillnet
	Target species	Plaice
Twine	Diameter	0.30 mm
	Type	Monofil
	Material	Nylon
	Color	Snow-white
	Knot	Double
Mesh size	Nominal (bar length)	68 mm
Dimensions	Height (mesh depth)	2 m (14.5)
	Length (No. of knots)	82 m (4800 kn)
	Hanging ratio	25%
Floatline	Buoyancy per 100 m	900 g
Leadline	Weight per 100 m	5 kg

Table 2. Mean and range (min-max) number, length of individuals caught per fleet (3 individual nets for a total length of 246m) relative abundance (min-max) and occurrence per soak tactic (12hD for 12h at day, 12hN for 12h at night and 24h for 24h) for invertebrates and fish species. Length is pooled over fleets, and given in mm for invertebrates and in cm for fish.

Species	Soak	Number	Length	Relative abundance (%)	Occurrence (%)
INVERTEBRATES					
Edible crab *(Cancer pagurus)*	12hD	9 (1-29)	114 (66-194)	13.5 (4.2-39.7)	71
	12hN	26 (10-80)	117 (58-197)	46.4 (23.8-77.3)	100
	24h	30 (7-74)	118 (57-193)	35.5 (14.9-58.7)	100
Common shore crab *(Carcinus maenas)*	12hD	2 (1-4)	56 (38-69)	5.9 (0.4-15.4)	57
	12hN	2 (1-4)	60 (50-68)	5.6 (1.1-13.3)	43
	24h	3 (1-11)	58 (36-70)	3.7 (0.8-16.9)	90
Common starfish *(Asterias rubens)*	12hD	4 (1-10)	104 (31-167)	7.6 (2.0-14.3)	29
	12hN	5 (1-16)	108 (54-186)	6.2 (2.0-13.1)	24
	24h	1 (1-2)	102 (39-164)	2.2 (1.2-5.1)	38
Edible sea urchin *(Echinus esculentus)*	12hD	-	-	-	-
	12hN	-	-	-	-
	24h	1	105	1.5	5
Hermit crab *(Pagurus bernhardus)*	12hD	-	-	-	-
	12hN	-	-	-	-
	24h	2 (1-3)	NA	2.5 (0.8-5.4)	14
Northern starfish *(Leptasterias muelleri)*	12hD	1 (1-1)	118 (118-119)	3.1 (3.0-3.2)	10
	12hN	2 (1-4)	103 (67-152)	3.8 (1.5-6.5)	24
	24h	1	158	1.0	5
Spiny starfish *(Marthasterias glacialis)*	12hD	1 (1-1)	112 (100-125)	3.3 (1.4-5.3)	10
	12hN	1	140	1.0	5
	24h	-	-	-	-
Swimming crab *(Liocarcinus depurator)*	12hD	3 (1-4)	41 (19-49)	7.2 (0.6-16.7)	57
	12hN	1 (1-2)	43 (37-50)	3.0 (0.8-6.9)	38
	24h	1 (1-2)	46 (40-58)	1.5 (0.7-2.4)	52
FISH					
Atlantic cod *(Gadus morhua)*	12hD	4 (1-10)	35 (22-53)	6.5 (0.8-13.7)	33
	12hN	3 (1-9)	36 (27-46)	4.2 (0.8-13.0)	29
	24h	2 (1-4)	30 (19-40)	2.3 (1.1-6.2)	43
Atlantic herring *(Clupea harengus)*	12hD	1	22	0.4	5
	12hN	-	-	-	-
	24h	2 (1-3)	36 (24-44)	2.2 (1.5-3.6)	19
Atlantic mackerel *(Scomber scombrus)*	12hD	1 (1-1)	33 (29-37)	2.6 (2.6-2.7)	10
	12hN	1 (1-1)	32 (30-34)	1.2 (0.8-1.5)	14
	24h	1	30	1.2	5
Brill *(Scophthalmus rhombus)*	12hD	-	-	-	-
	12hN	1	28	1.1	5
	24h	-	-	-	-
Common dab *(Limanda limanda)*	12hD	6 (1-14)	25 (19-31)	16.4 (3.1-33.3)	100
	12hN	7 (1-24)	26 (19-37)	12.2 (1.4-19.7)	100
	24h	13 (2-31)	25 (18-32)	15.7 (3.1-33.3)	100
Common sole *(Solea solea)*	12hD	-	-	-	-
	12hN	2 (1-4)	34 (23-39)	2.6 (0.8-5.8)	43
	24h	1 (1-2)	35 (30-39)	1.6 (0.8-2.0)	33
European flounder *(Platichthys flesus)*	12hD	2 (1-3)	32 (29-35)	2.5 (0.8-4.8)	19
	12hN	1 (1-1)	32 (26-37)	2.1 (0.8-4.3)	14
	24h	2 (1-3)	30 (21-37)	2.0 (0.8-6.4)	38

European plaice *(Pleuronectes platessa)*	12hD	31 (6-206)	31 (21-47)	53.2 (28.6-89.5)	100
	12hN	20 (4-58)	31 (21-53)	30.9 (13.3-48.8)	95
	24h	26 (8-73)	31 (20-46)	34.8 (12.3-58.0)	100
Garfish *(Belone belone)*	12hD	1	65	4.3	5
	12hN	-	-	-	-
	24h	-	-	-	-
Greater weever *(Trachinus draco)*	12hD	2 (1-3)	34 (29-38)	6.0 (0.4-13.6)	38
	12hN	1	35	1.8	5
	24h	2 (1-4)	32 (26-39)	2.6 (1.2-7.3)	48
Lemon sole *(Microstomus kitt)*	12hD	1	29	3.0	5
	12hN	-	-	-	-
	24h	2	28 (26-29)	3.1	5
Pollack *(Pollachius pollachius)*	12hD	2	35 (30-40)	5.1	5
	12hN	-	-	-	-
	24h	-	-	-	-
Saithe *(Pollachius virens)*	12hD	1	28	1.4	5
	12hN	1	29	1.3	5
	24h	1	35	1.5	5
Sculpin *(Myoxocephalus spp.)*	12hD	-	-	-	-
	12hN	-	-	-	-
	24h	1	24	1.2	5
Tadpole fish *(Raniceps raninus)*	12hD	-	-	-	-
	12hN	-	-	-	-
	24h	1	25	1.5	5
Turbot *(Psetta maxima)*	12hD	2 (1-4)	25 (19-36)	2.7 (1.2-5.1)	48
	12hN	2 (1-4)	24 (19-35)	4.0 (2.3-6.7)	57
	24h	3 (1-9)	23 (18-34)	3.9 (1.2-12.2)	76
Twaite shad *(Alosa fallax)*	12hD	1 (1-2)	34 (22-41)	1.4 (0.4-2.7)	29
	12hN	-	-	-	-
	24h	2 (1-2)	27 (23-34)	1.6 (1.0-2.2)	10
Whiting *(Merlangius merlangus)*	12hD	2 (1-2)	18 (12-24)	5.5 (0.4-11.8)	19
	12hN	1	15 (14-16)	1.3 (1.0-1.8)	14
	24h	2 (1-2)	13 (11-17)	2.3 (1.8-2.7)	14
Red gurnard *(Chelidonichthys lucernus)*	12hD	1 (1-2)	25 (19-29)	5.3 (2.7-11.8)	38
	12hN	1 (1-1)	30 (22-39)	2.1 (0.8-4.5)	29
	24h	2 (1-3)	26 (20-31)	2.1 (0.7-3.6)	33

Table 3. Catch ratio results and fit statistics obtained in the catch comparison analysis for European plaice, common dab and edible crab. p-value, deviance and degrees of freedom (DOF) are given as bias corrected mean. *cr*(20, ***v***) is the catch ratio at species size 20 cm. Values in () represent 95% confidence limits.

	12hN (baseline: 12hD)	24h (baseline: 12hD)	24h (baseline: 12hN)
EUROPEAN PLAICE			
*cr(20,**v**)*	0.55 (0.05-1.89)	0.66 (0.03-2.03)	1.22 (0.23-6.10)
*cr(25,**v**)*	0.60 (0.24-1.72)	0.77 (0.34-2.00)	1.29 (0.78-2.48)
*cr(30,**v**)*	0.61 (0.30-1.40)	0.84 (0.47-1.91)	1.37 (0.88-2.20)
cr(35, ***v***)	0.64 (0.31-1.22)	0.92 (0.47-1.72)	1.44 (0.88-2.45)
cr(40, ***v***)	0.72 (0.29-1.47)	1.07 (0.50-2.48)	1.47 (0.80-3.34)
cr(45, ***v***)	0.92 (0.21-6.09)	1.44 (0.43-62.28)	1.43 (0.47-20.03)
cr(50, ***v***)	1.45 (0.10-135.25)	2.13 (0.23-1.19*105)	1.25 (0.12-205.08)
cr(55, ***v***)	2.36 (0.06-2.52*103)	2.81 (0.13-4.96*109)	1.02 (0.01-677.48)
$cr_{average}$ <MCRS (%)	47.83 (18.72-150.00)	61.96 (26.60-188.57)	129.55 (68.63-272.73)
$\Delta\ cr_{average}$ <MCRS (%)	-52.17 (-81.28 to 50.00)	-38.04 (-73,4 to 88.57)	29.55 (-31.37 to 172.73)
$cr_{average}$ >MCRS (%)	64.73 (31.92-133.12)	90.18 (49.89-180.45)	139.33 (93.64-223.23)
$\Delta\ cr_{average}$ >MCRS (%)	-35.27 (-68.08 to 33.12)	-9.82 (-50.11 to 80.45)	39.33 (-6.36 to 123.23)
p-value	0.0399	0.2177	0.0815
Deviance	37.39	27.95	34.18
DOF	24	23	24
COMMON DAB			
*cr(15,**v**)*	0.57 (0.00-2.20)	1.59 (0.05-5.76)	2.35 (0.50-315.93)
*cr(20,**v**)*	0.87 (0.23-2.31)	2.07 (0.65-4.72)	2.19 (0.92-6.70)
*cr(25,**v**)*	1.11 (0.70-1.87)	2.13 (1.38-3.37)	1.96 (1.13-3.20)
*cr(30,**v**)*	1.09 (0.29-2.28)	1.64 (0.56-3.34)	1.47 (0.74-4.57)
*cr(35,**v**)*	2.17 (0.05-30.53)	0.93 (0.02-7.97)	0.54 (0.03-13.76)
*cr(40,**v**)*	3.26 (0.09-34 625.83)	0.55 (0.01-15.84)	0.20 (0.00-13.59)
$cr_{average}$ (%)	108.26 (68.71-164.08)	204.13 (132.43-293.41)	188.55 (120.57-299.11)
$\Delta\ cr_{average}$ (%)	8.26 (-31.29 to 64.08)	104.13 (32.43 to 193.41)	88.55 (20.57 to 199.11)
p-value	0.0087	0.1333	0.1613
Deviance	23.63	14.97	15.49
DOF	10	10	11
EDIBLE CRAB			
*cr(55,**v**)*	2.06 (0.13-8.43)	1.53 (0.12-7.39)	0.86 (0.09-5.39)
*cr(65,**v**)*	2.37 (0.46-8.16)	1.89 (0.34-6.43)	0.91 (0.19-2.17)
*cr(75,**v**)*	2.72 (1.27-8.12)	2.36 (0.94-6.67)	0.96 (0.38-1.50)

*cr(85,**v**)*	3.11 (1.71-8.23)	2.94 (1.40-7.98)	1.02 (0.56-1.45)
*cr(95,**v**)*	3.55 (1.96-8.93)	3.65 (1.76-9.79)	1.07 (0.64-1.59)
*cr(105,**v**)*	4.00 (2.22-10.37)	4.45 (2.20-11.32)	1.12 (0.71-1.73)
*cr(115,**v**)*	4.44 (2.32-12.00)	5.28 (2.52-13.23)	1.17 (0.80-1.85)
*cr(125,**v**)*	4.81 (2.44-14.01)	6.02 (2.90-15.64)	1.20 (0.82-1.94)
*cr(135,**v**)*	5.08 (2.52-15.43)	6.53 (3.11-17.07)	1.22 (0.82-1.95)
*cr(145,**v**)*	5.16 (2.55-16.26)	6.64 (3.19-18.63)	1.23 (0.78-1.96)
*cr(155,**v**)*	5.02 (2.55-18.22)	6.24 (3.05-18.05)	1.22 (0.69-1.96)
*cr(165,**v**)*	4.62 (2.24-20.31)	5.31 (2.17-19.68)	1.19 (0.50-2.14)
*cr(175,**v**)*	3.96 (1.31-29.56)	4.01 (0.98-29.86)	1.14 (0.25-3.38)
*cr(185,**v**)*	3.12 (0.47-50.20)	2.63 (0.29-53.61)	1.07 (0.09-7.99)
*cr(195,**v**)*	12.23 (0.09-80.84)	1.48 (0.06-76.06)	0.99 (0.03-31.59)
*cr(200,**v**)*	1.82 (0.03-95.90)	1.06 (0.02-86.91)	0.94 (0.02-78.93)
$cr_{average}$ (%)	415.50 (234.05-910.53)	475.97 (268.07-986.57)	114.55 (78.12-168.59)
Δ $cr_{average}$ (%)	315.50 (134.05 to 810.53)	375.97 (168.07 to 886.57)	14.55 (-21.88 to 68.59)
p-value	0.0851	0.4408	0.3536
Deviance	126.50	104.48	114.98
DOF	106	103	110

Fig. 1. Sampling design

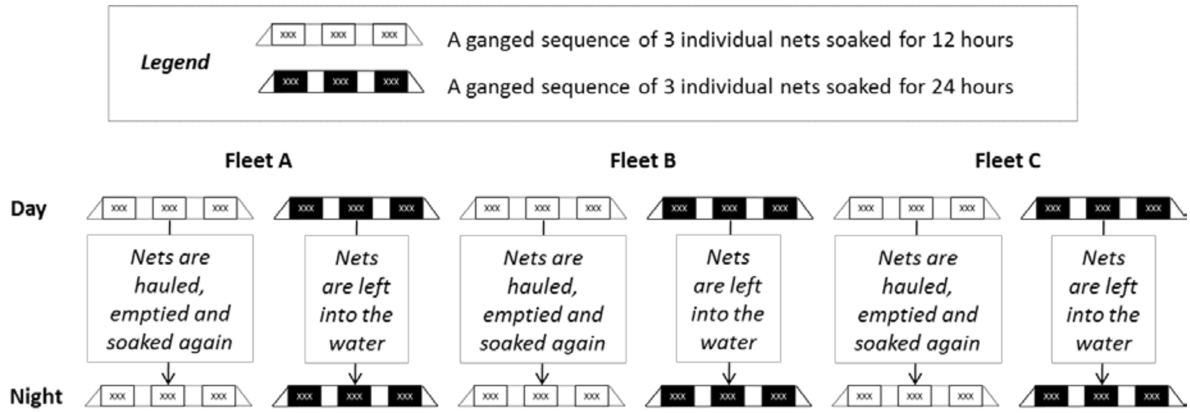


Fig. 2. Time in the day when fleets were soaked by sampling day (from I to VII). Civil twilight was used to define dawn and dusk. Fleets were labelled as a combination of soak tactic (12hD for 12h at day, 12hN for 12h at night and 24h for 24h) and fleet identification (A, B or C).

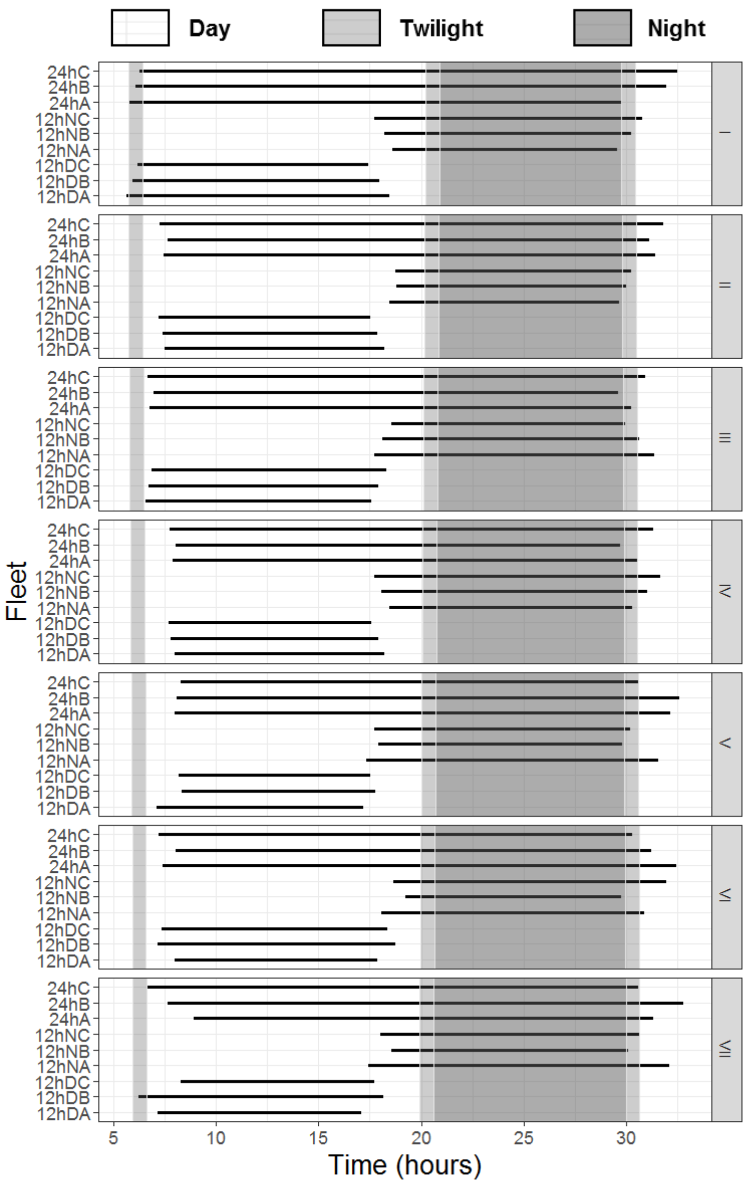
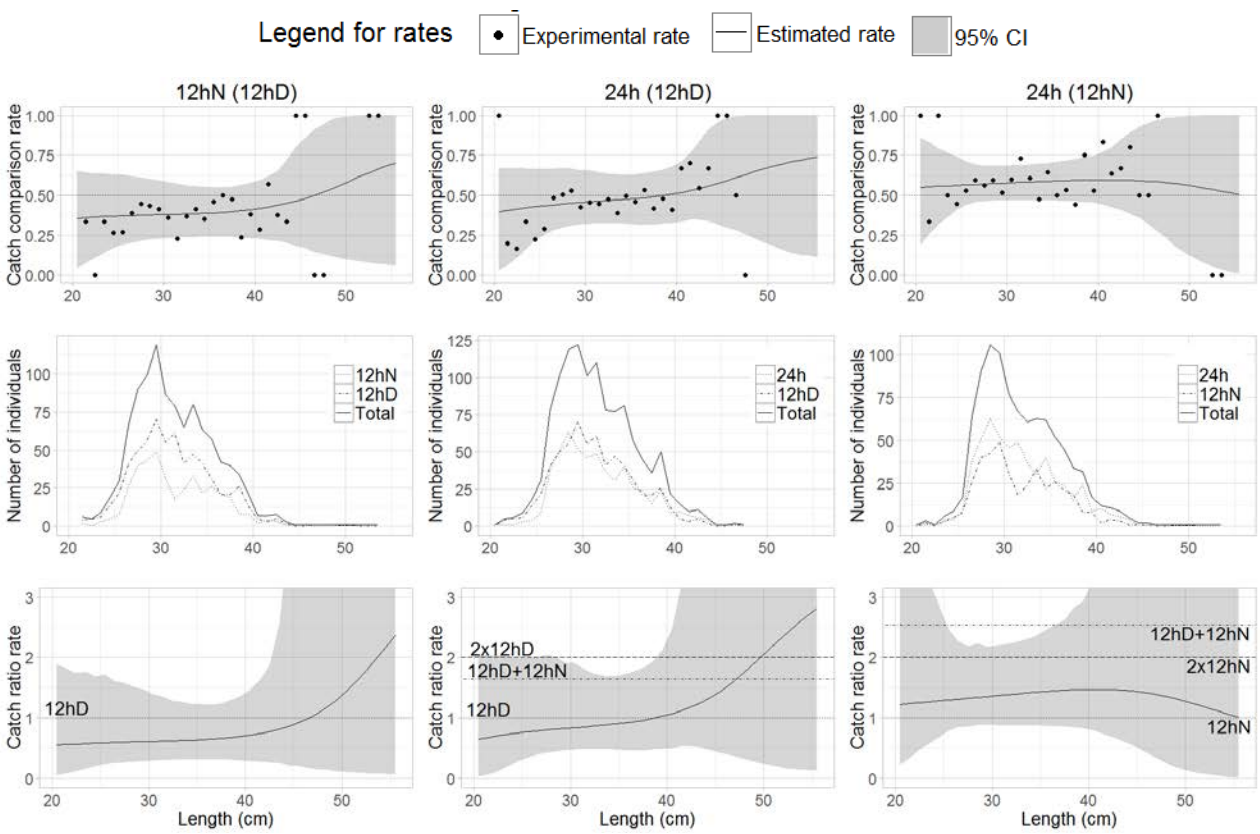
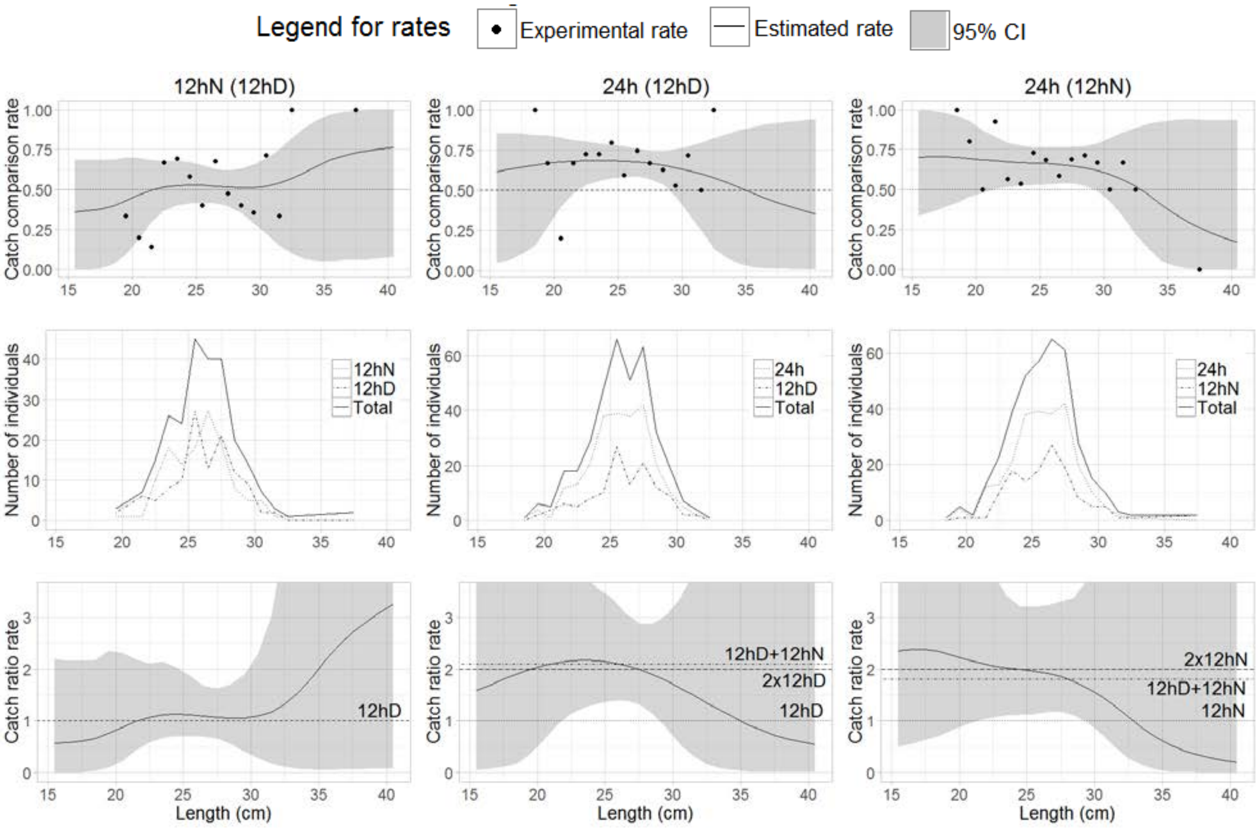


Fig. 3. Catch comparison rate (upper row), population curve (middle) and catch ratio (lower row) for the three catch comparison analysis of different soak tactics, i.e., 12h at night (12hN) compared to 12h at day (12hD) (left column), 24h (24h) compared to 12hD (middle column) and 24h compared to 12hN (right column), estimated for (a) European plaice, (b) common dab and (c) edible crab. The catch comparison rates ('Estimated rate', black curve) are given with the Efron 95% confidence interval ('95% CI', shaded area), the experimental rates ('Experimental rate', points) and the expected rate in case of no effect of the soak tactics change investigated (horizontal stippled line). The population curves are given for the summed population per soak tactic and the summed total population. The catch ratios ('Estimated rate', black curve) are given with the Efron 95% confidence interval ('95% CI', shaded area) and the expected ratio in case of no effect of the soak tactic change investigated (12hD=24h or 12hN=24h), 2 times more catch in 24h than in the (2x12hD, 2x12hN), or 24h catch as the summed of the estimated 12hD and 12hN catch based on the results of the comparison 12hN compared to 12hD (12hD+12hN) (horizontal stippled lines).

(a) European plaice



(b) Common dab



Legend for rates
Experimental rate
Estimated rate
95% CI
12hN (12hD)
24h (12hD)
24h (12hN)
Catch comparison rate
Number of individuals
12hN
12hD
Total
24h
Catch ratio rate
12hD
12hD+12hN
2x12hD
2x12hN
12hN
Length (cm)

(c) Edible crab

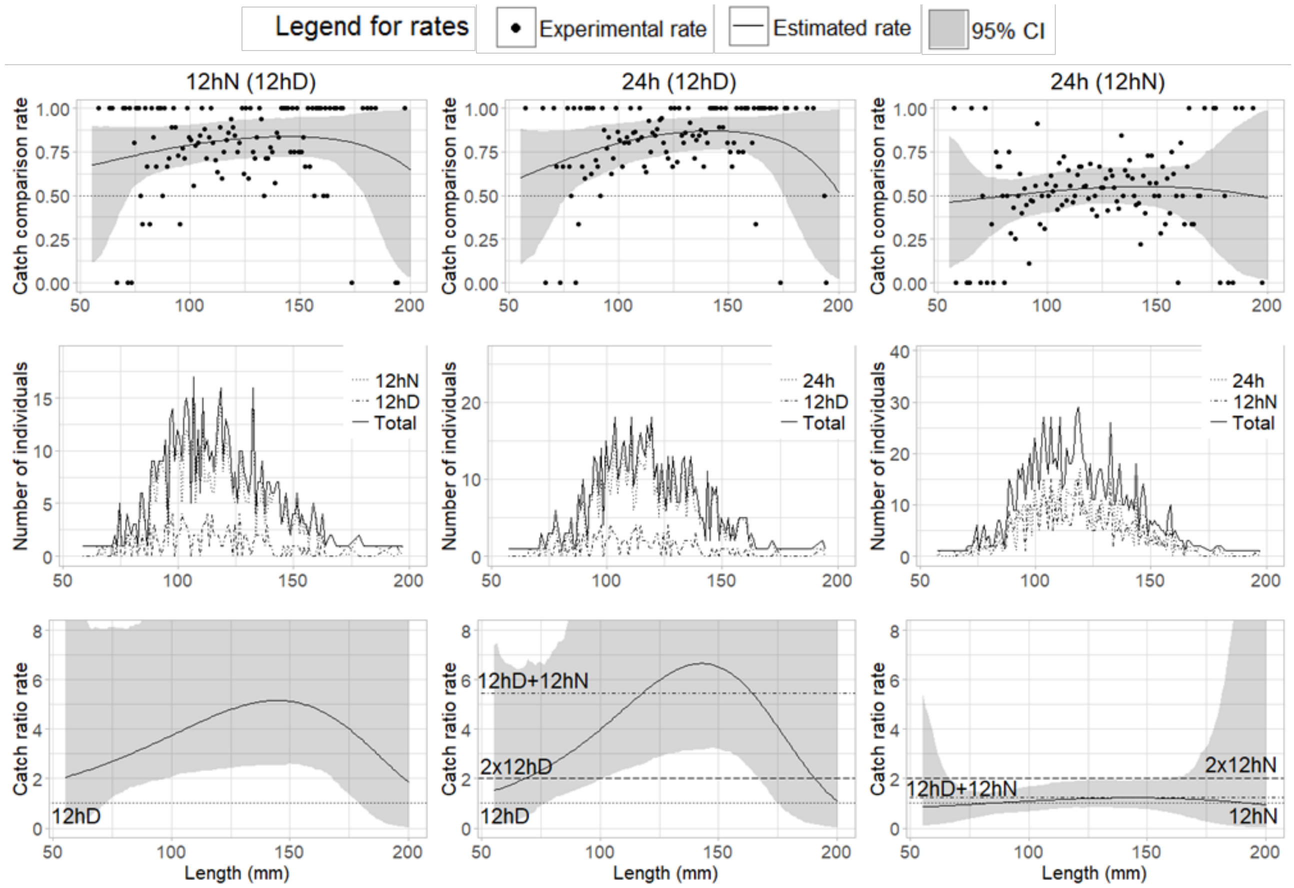


Fig. 4. Average changes in catch ratio for the different soak tactics compared: 12h at night compared to 12h at day (12hN_12hD), 24h compared to 12h at day (24h_12hD), 24h compared to 12h at night (24h_12hN) for edible crab (1st column), common dab (2nd column), and European plaice below (3rd column) and above (4th column) MCRS (27cm). The vertical bars represent the Efron 95% confidence intervals.